Thermoplastic Composites Conference

Thermoplastic Aircraft Frame Production using AFP and Stamp Forming

March 23, 10:45 – 11:00am

Ron Jones

Spirit Aerosystems

ACMA American Composites Manufacturers Association

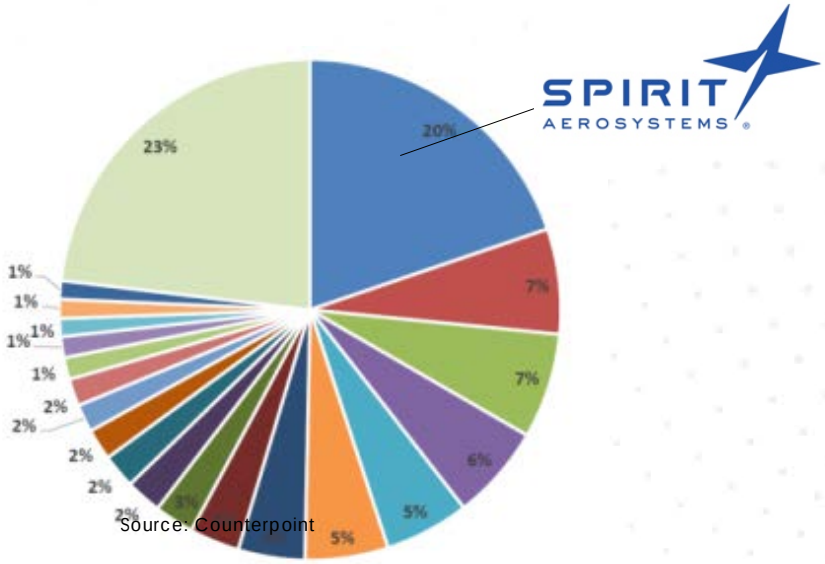
Acknowledgements

- Ron Jones
- Matt Tymes
- Joe Garber

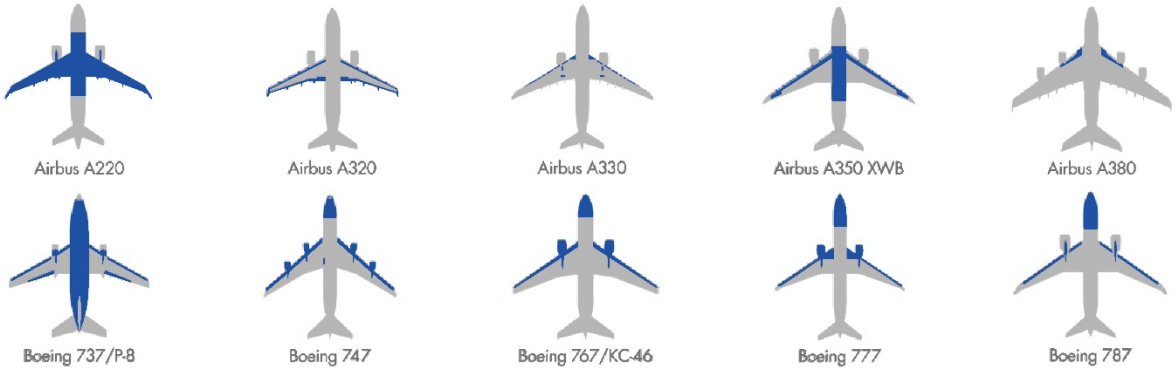
- Michael Assadi
- Ryan Jordan

- Rich Postera
- David Leach

Spirit Is the Leading Global Aerostructures Tier 1 Supplier



On all of 12,500 Boeing/Airbus backlog



SPR backlog = $47.9B

With a balanced aerostructures portfolio

Fuselage (52%)

Propulsion (26%)

Wing (21%)

And an emerging presence in Defense

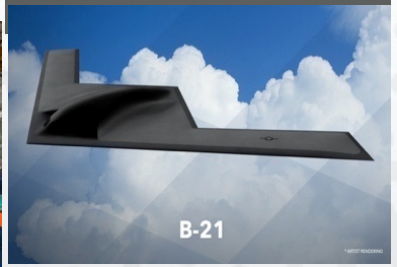
Sikorsky CH-53K

Bell V-280

P-8A, P-8I

KC-46A Tanker

Northrop Grumman B-21



Growth Market Focus

DIVERSIFIED DESIGN AND MANUFACTURING CHAMPION

EMERGING STRONGER

DIVERSIFY • DE-LEVER • DRIVE MARGIN

ELECTROIMPACT

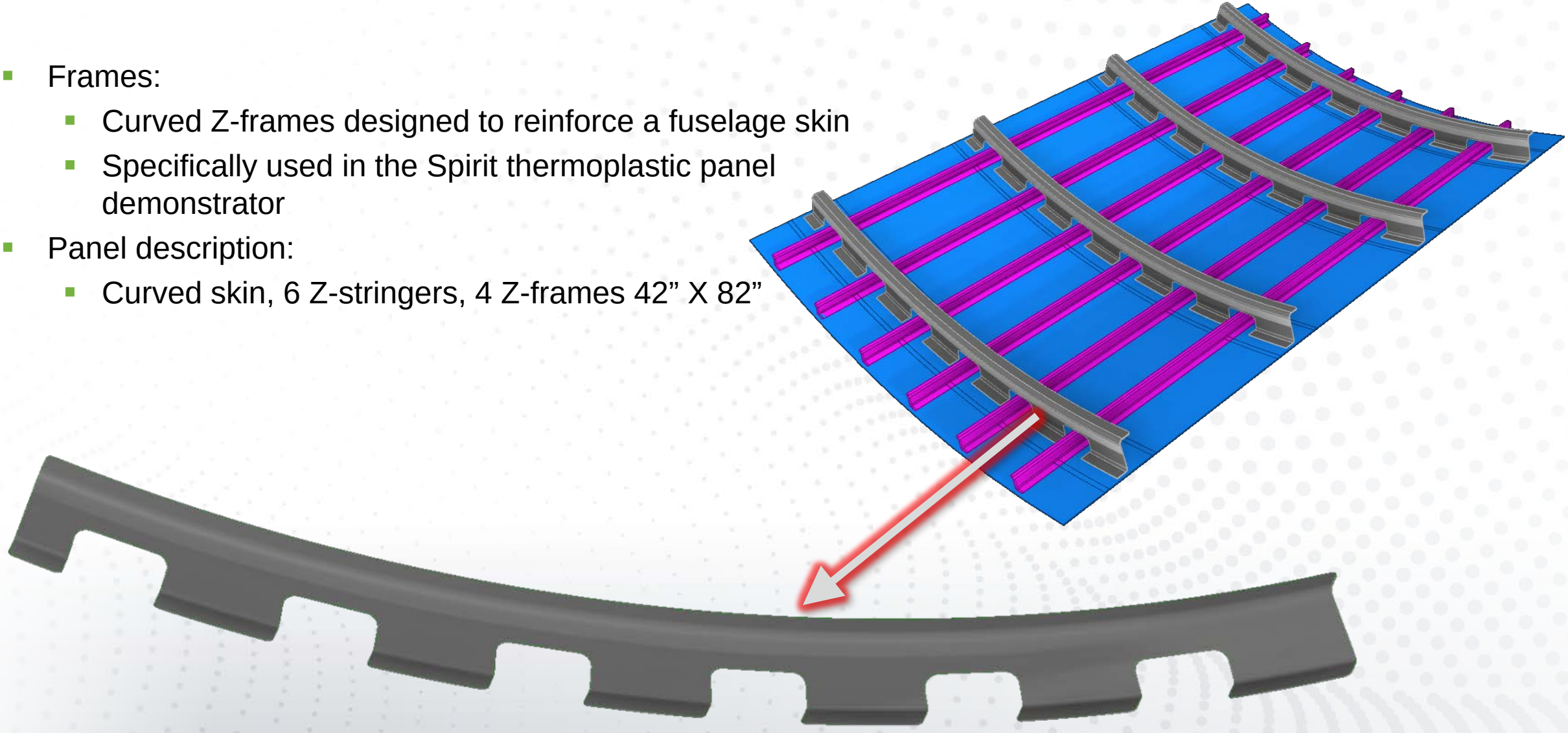
- Electroimpact is a world leader in the design and manufacture of aerospace tooling and automation
- Electroimpact's thermoplastic AFP machine fabricated the frame blanks

ATC ADVANCED THERMOPLASTIC COMPOSITES

- ATC is a leading manufacturer of continuous fiber reinforced thermoplastic components for aerospace applications
- ATC designed press tooling and formed the frame blanks

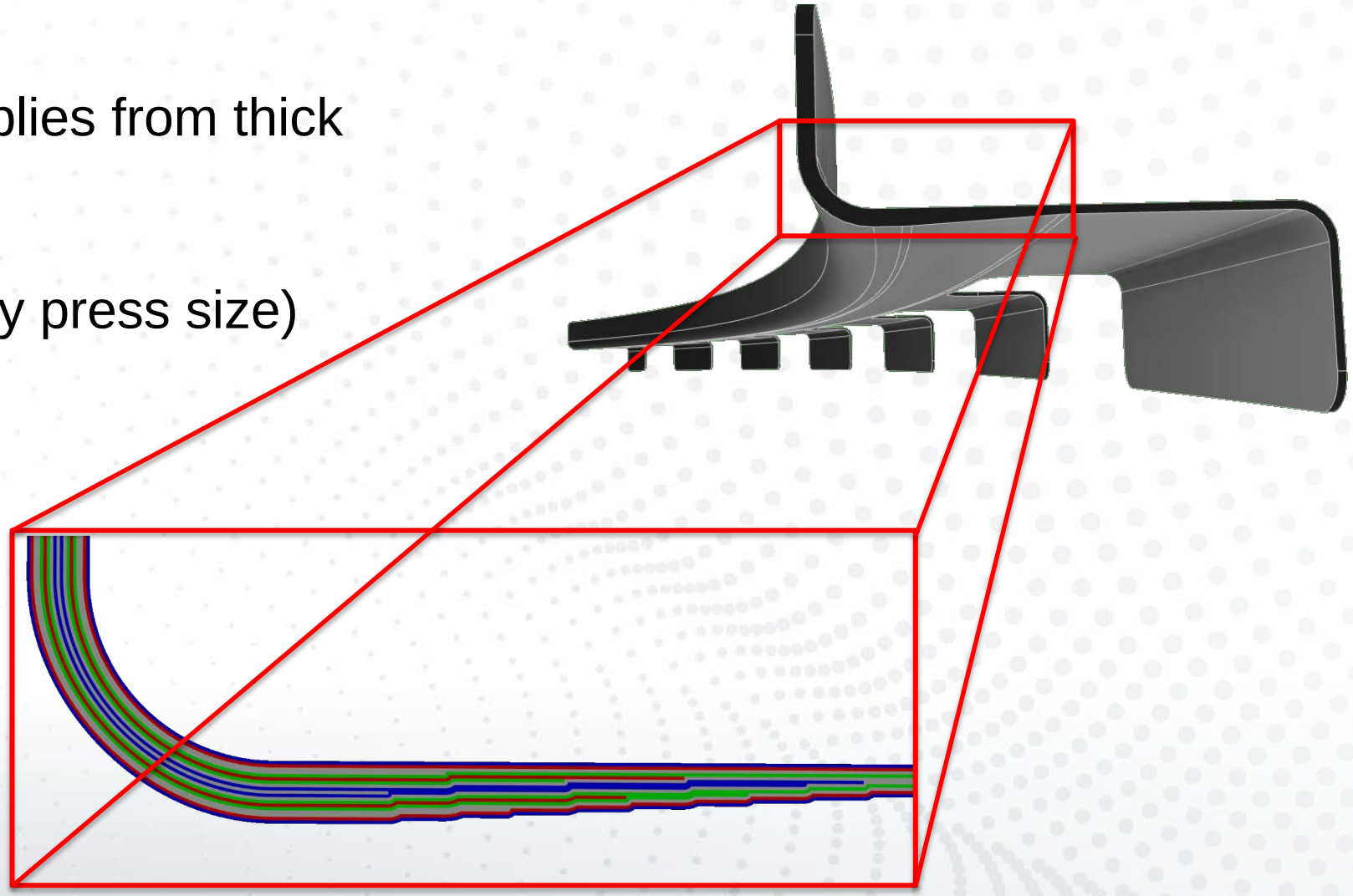
Frames Overview

- Frames:
  - Curved Z-frames designed to reinforce a fuselage skin
  - Specifically used in the Spirit thermoplastic panel demonstrator
- Panel description:
  - Curved skin, 6 Z-stringers, 4 Z-frames 42” X 82”



Frame Design

- 50% reduction in plies from thick side to thin side
- 52” long (limited by press size)
- 6 mouse holes

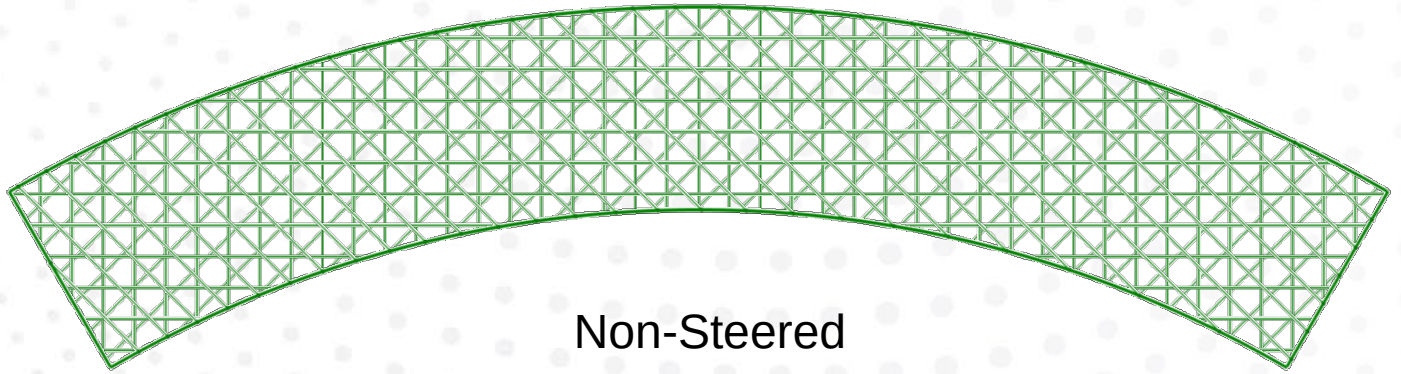


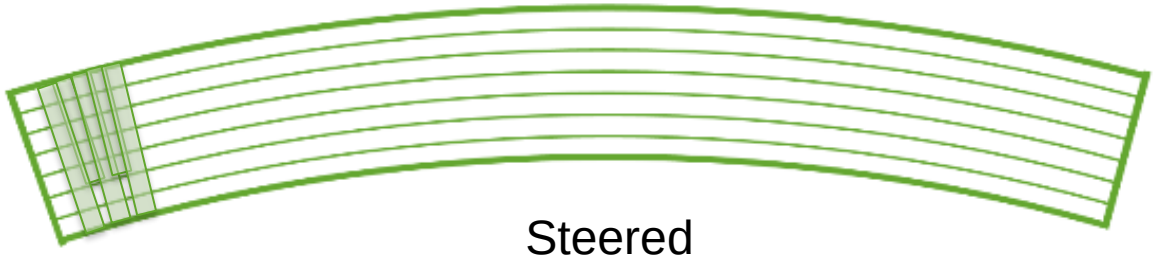
Frame cross-section

Frame Blank Design

- Non-Steered
  - Axis relative to XYZ, not oriented along the frame
  - No laps or gaps between tows

- Steered
  - Steered fibers in 0º
  - Other fibers oriented relative to 0º
  - Laps and gaps present when tows converge



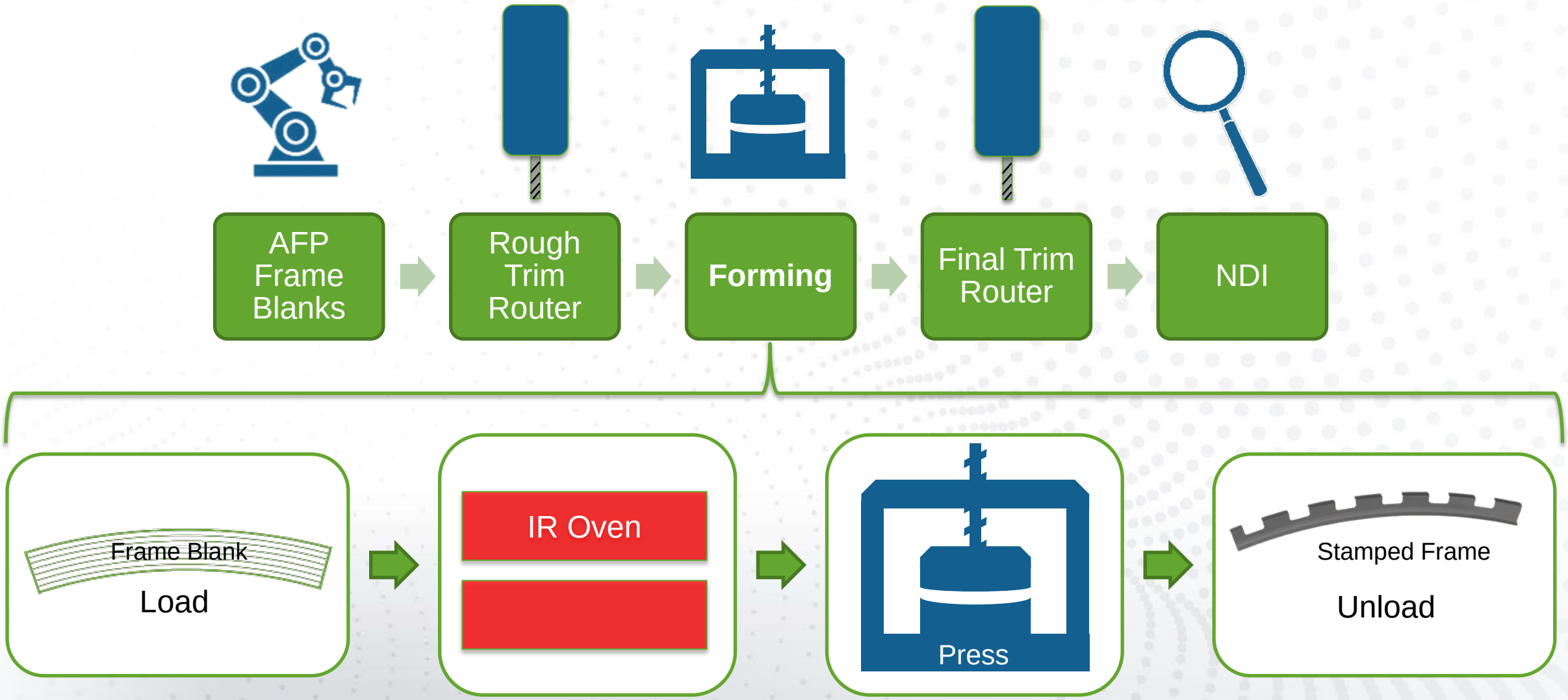


Frames - Material

- Trials have been done with both Toray PAEK and Solvay PEKK material
- This was done in anticipation of market needs and customer requirements

Property	Toray PAEK	Solvay PEKK
Fiber areal weight	145 g/m^2	145 g/m^2
Resin content by weight	34%	34%
Consolidated ply thickness	0.14 mm	0.14 mm
Resin density	1.30 g/cm^3	1.31 g/cm^3
T_g (glass transition)	297 ºF	318 ºF
T_m (melt)	581 ºF	639 ºF
T_c (crystallization)	505 ºF	534 ºF
T_p (processing)	644–725 ºF	702 - 783 ºF

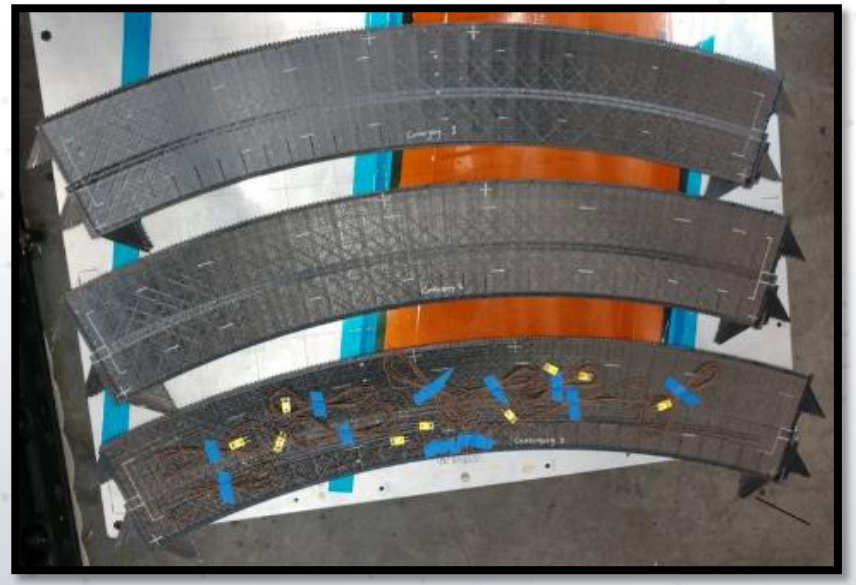
Frame Fabrication Overview



Automated Fiber Placement – Electroimpact

Electroimpact
AFP Machine

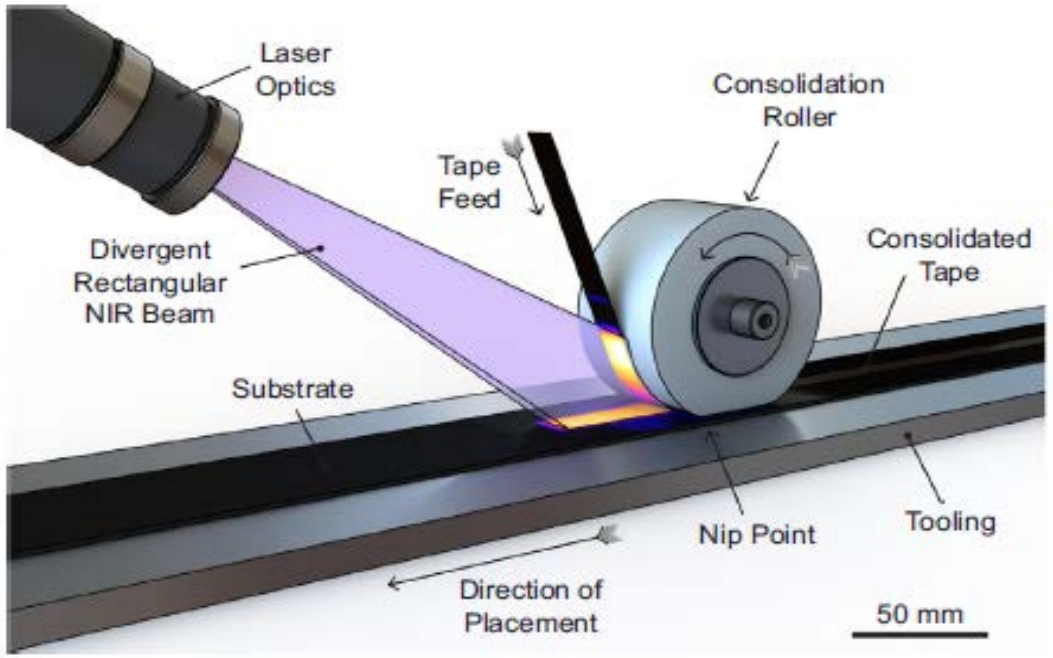
- Frame blanks were fabricated at Electoimpact (Mukilteo, Washington) with TP-AFP
- What is TP-AFP?
  - Thermoplastic Automated Fiber Placement is a composite fabrication method that lays down pre-preg tow
  - The tow is laid down quickly and lightly tacked together



AFP
Frame Blanks

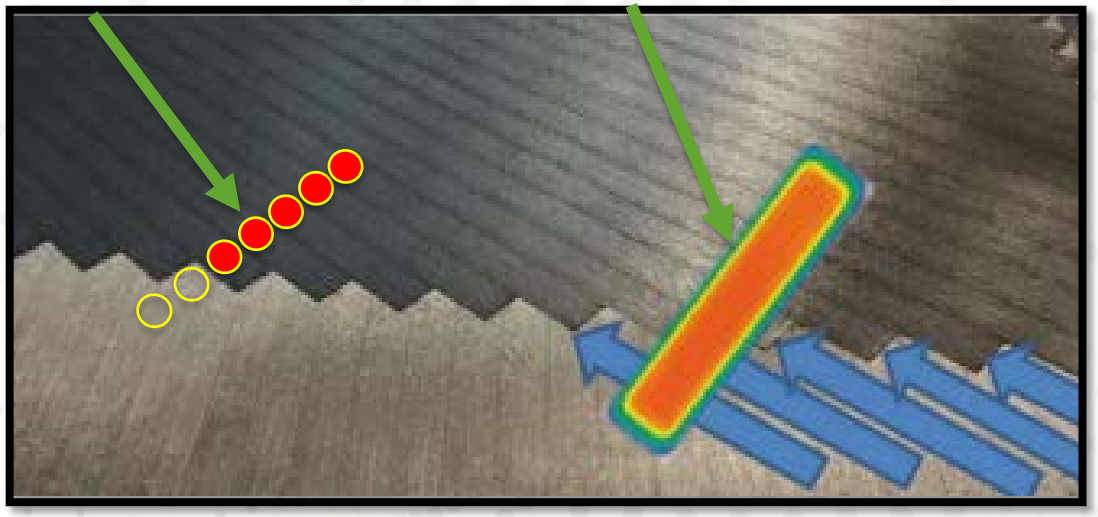
Automated Fiber Placement – Electroimpact

- Laser heating is required for thermoplastics, due to the high processing temperatures (>650 ºF)
- Started with laser line, moved to VSSL



Laser-assisted TP-AFP adapted from: Stokes-Griffin: "The effect of processing temperature and placement rate on the short beam strength of carbon fibre–PEEK manufactured using a laser tape placement process," Composites: Part A 78 (2015) 274–283.

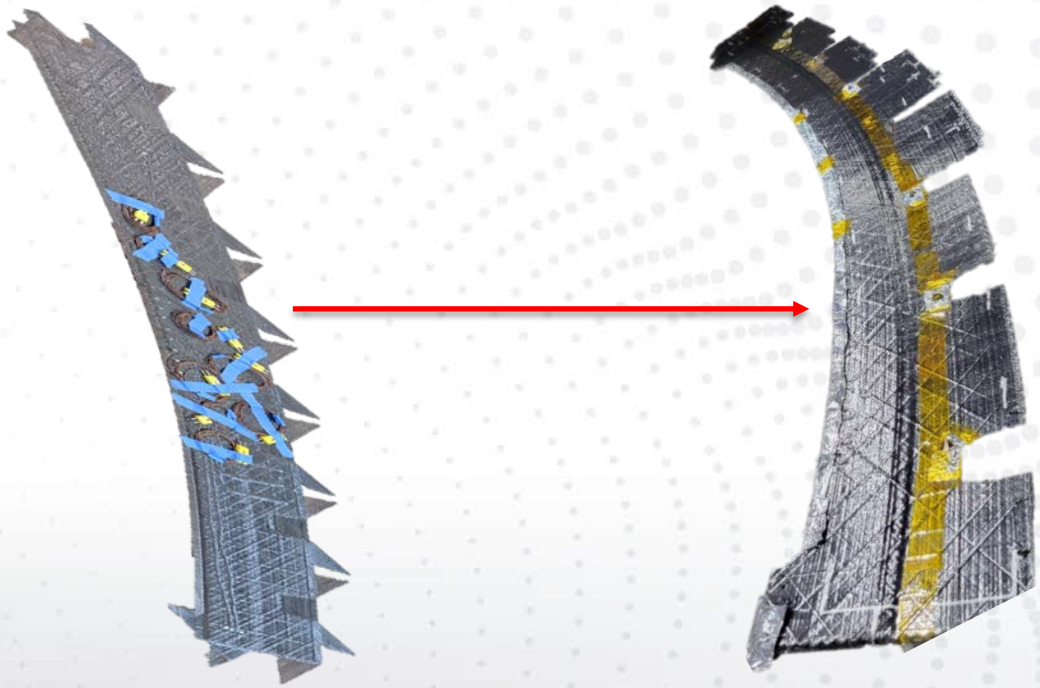
VSSL LaserLine



Laser line cannot adjust with tow drop, causing reheating of underlying plies

Rough Trim - ATC

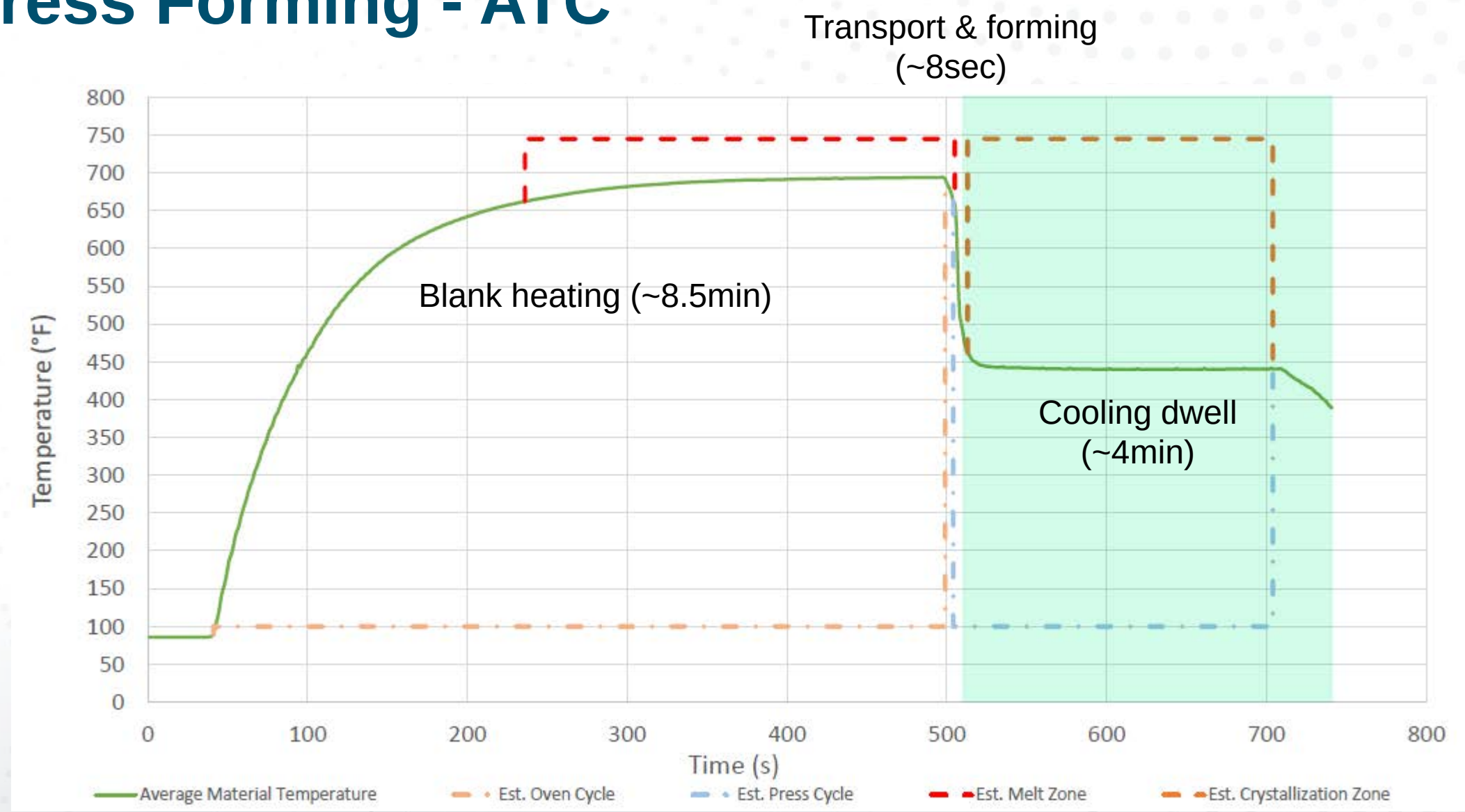
- Rough trim part and cut out mouse holes, allowing the material to bend without buckling
- When part is trimmed, the index points are also added, coordinating them to the part before press forming



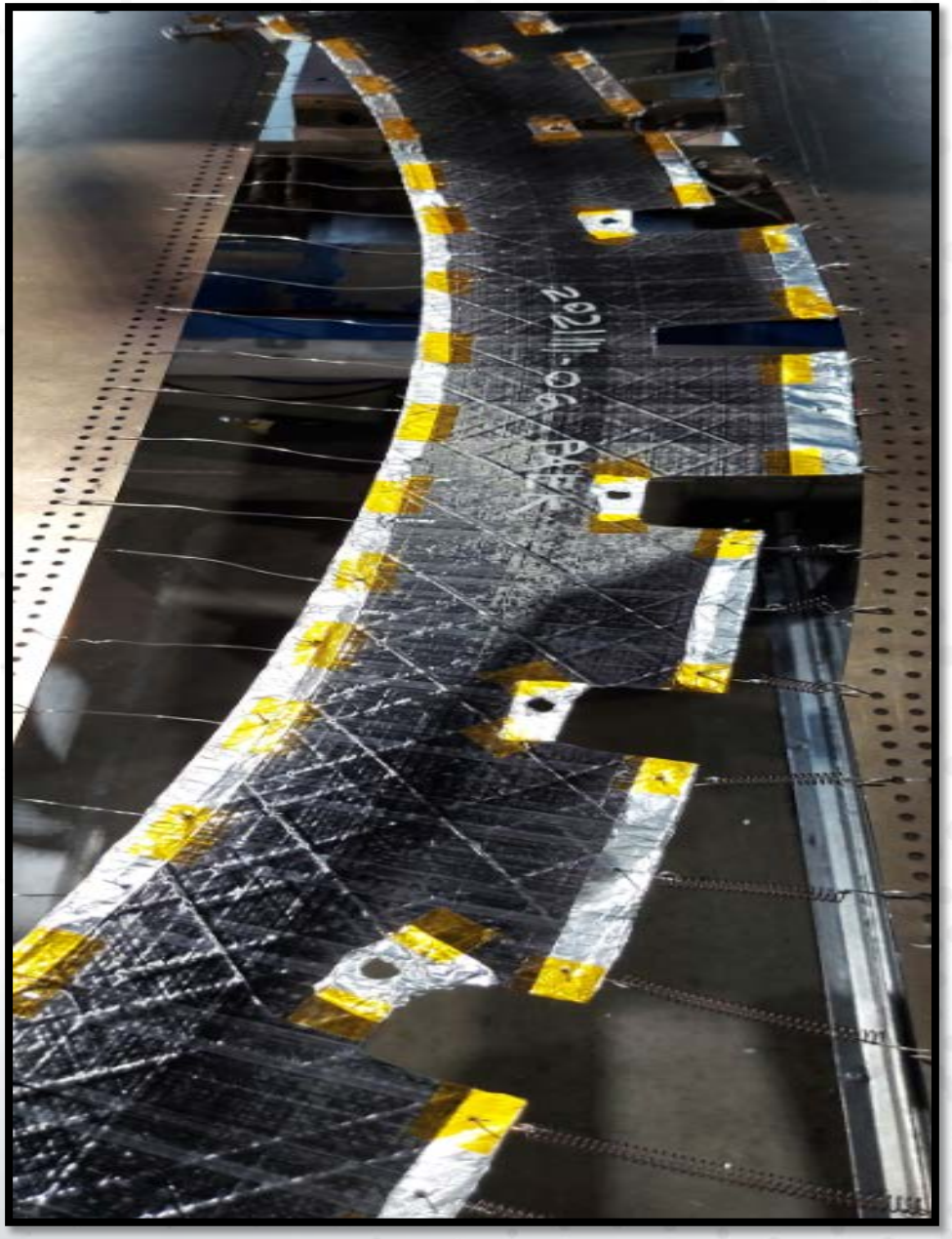
Frame blank before rough trim

Frame blank after rough trim

Press Forming - ATC

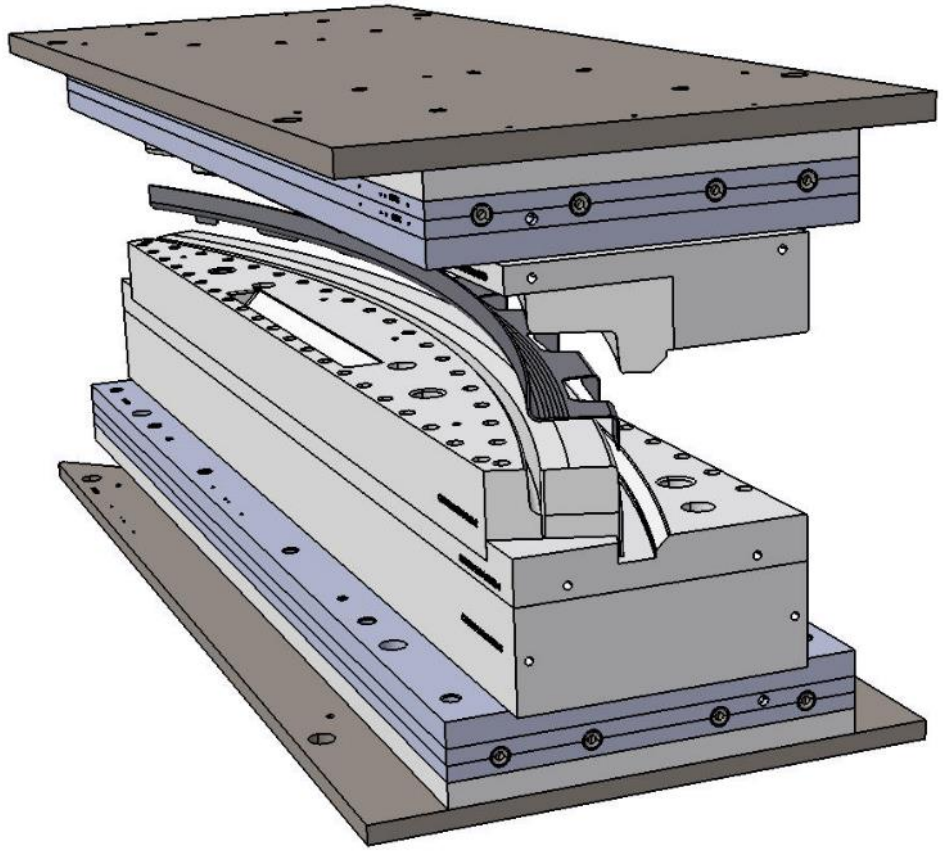


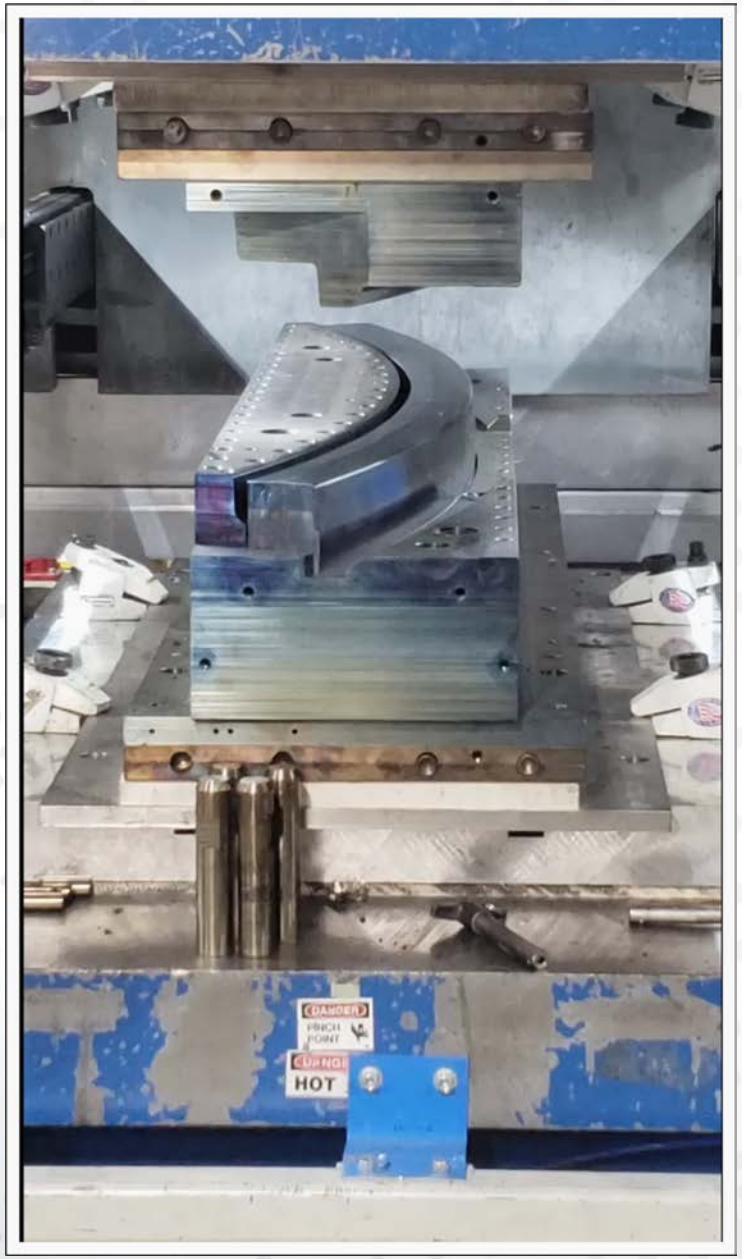
Press Forming – Flat Blank Loaded for Transfer to Oven



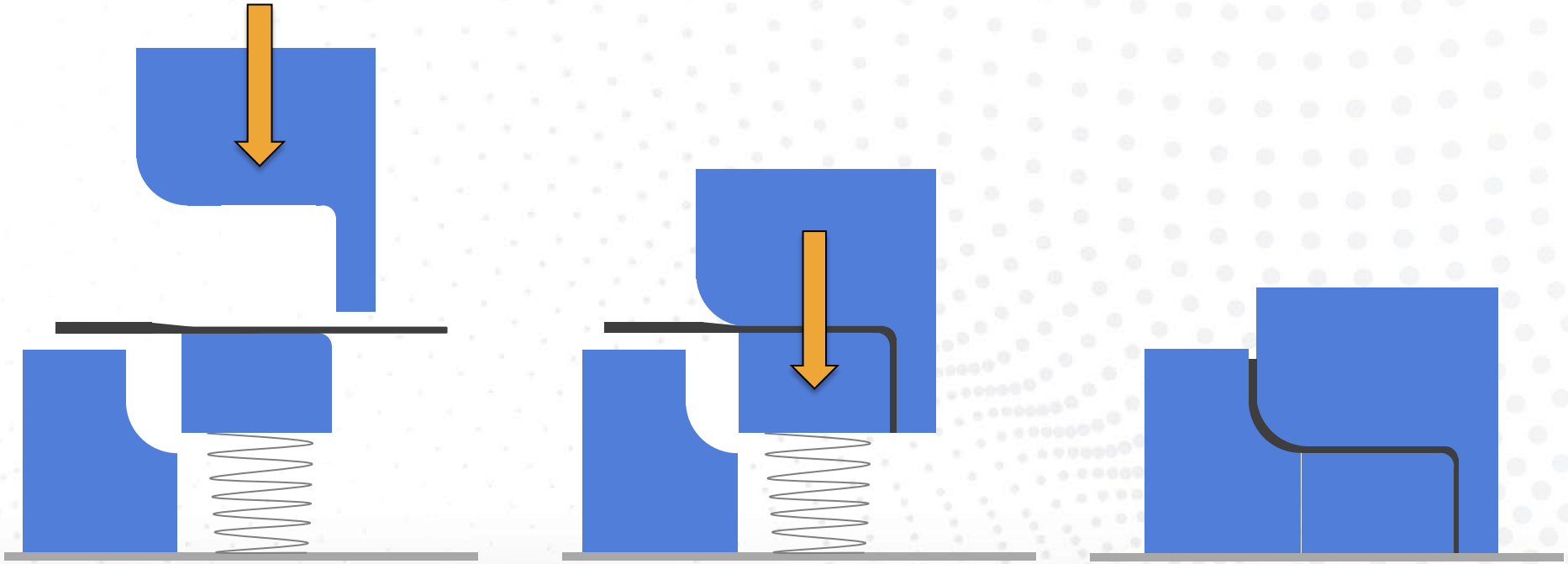
Tooling

- Tooling designed by ATC
- Innovative multi-step, multi-piece tool
- Spring-loaded center tool



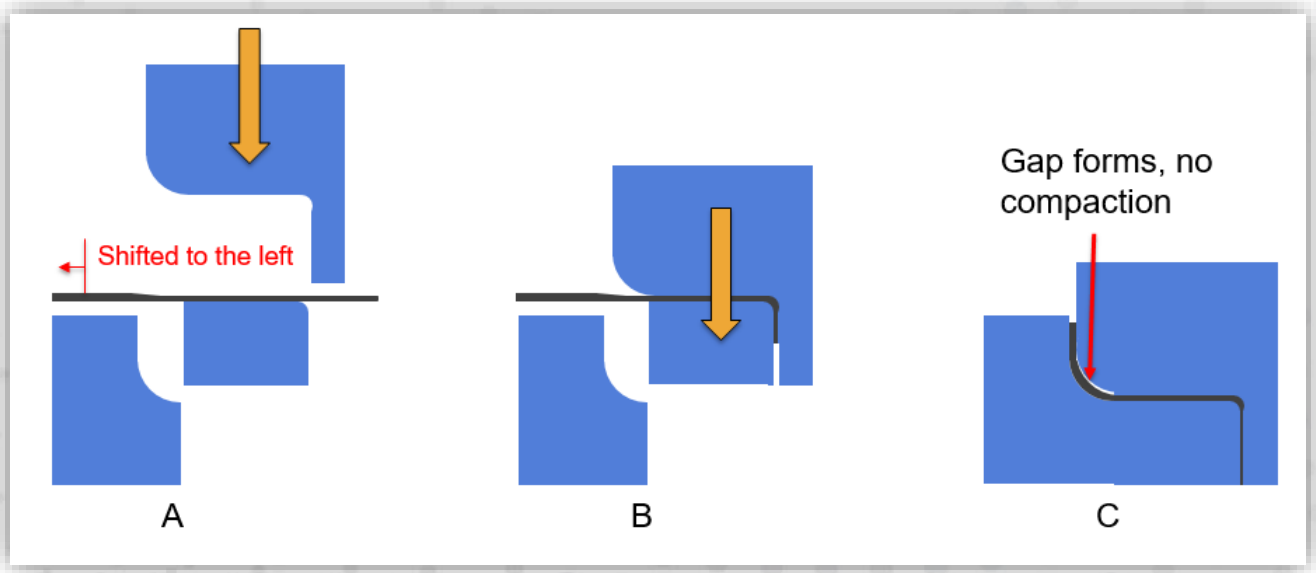


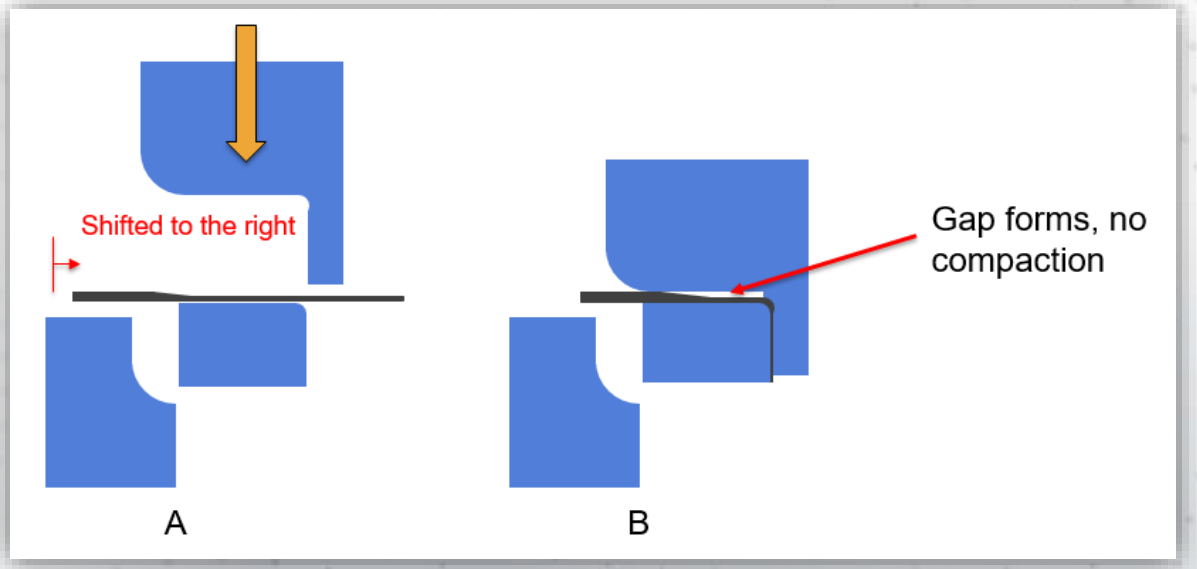
Perfect Blank/Tool Alignment



Alignment Challenges

Left shifted





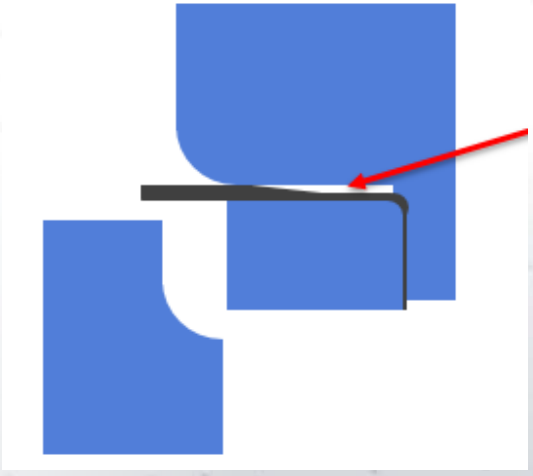
Right shifted

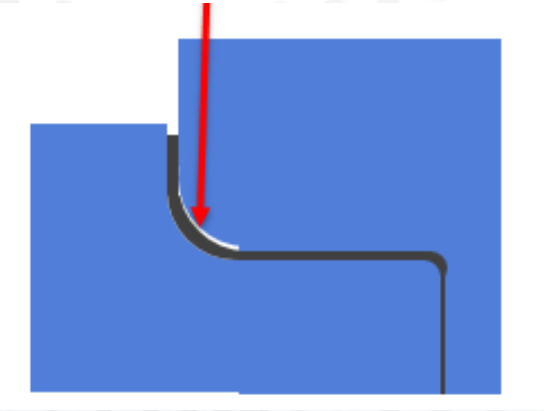
Resulting Defects…

Low compaction

Porosity

Low compaction





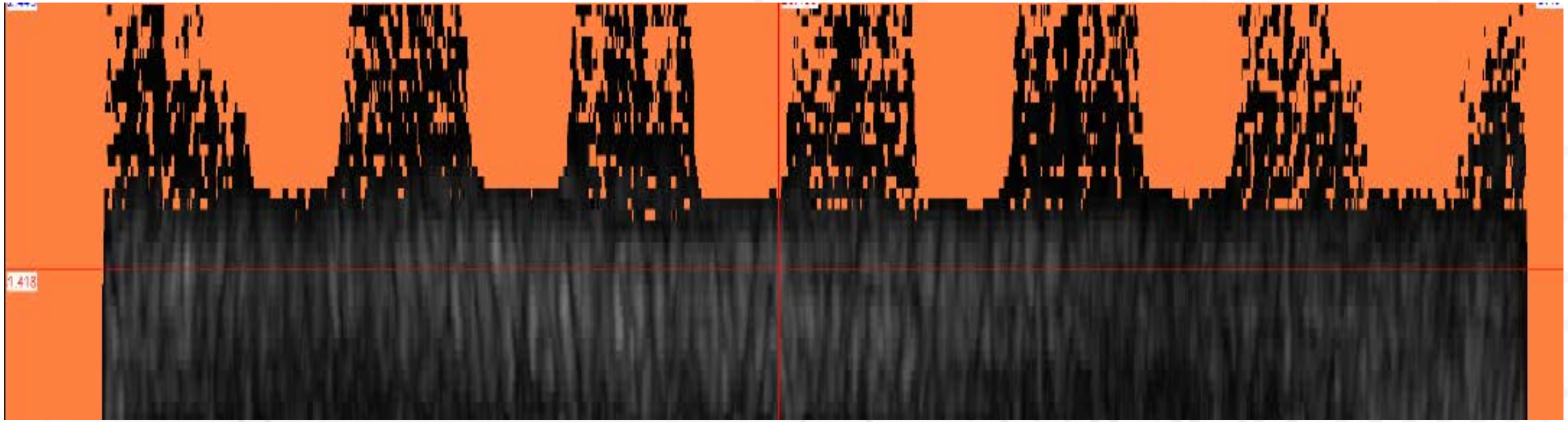
Forming Trials

- Initial parts had large wrinkles

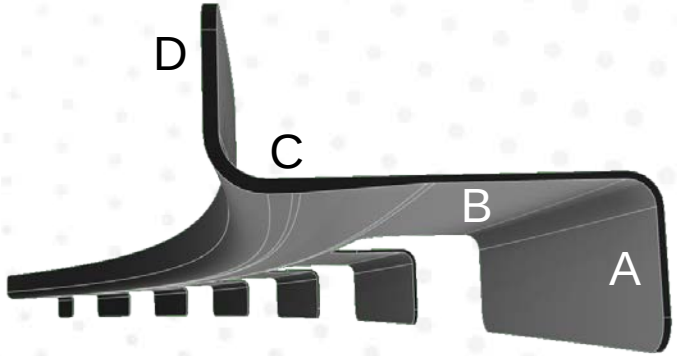
- Removed tool line up features to concentrate on blank alignment in the tool

Day 1 frame after stamping. Significant wrinkling seen on web attributed to tool line up features preventing full tool closure

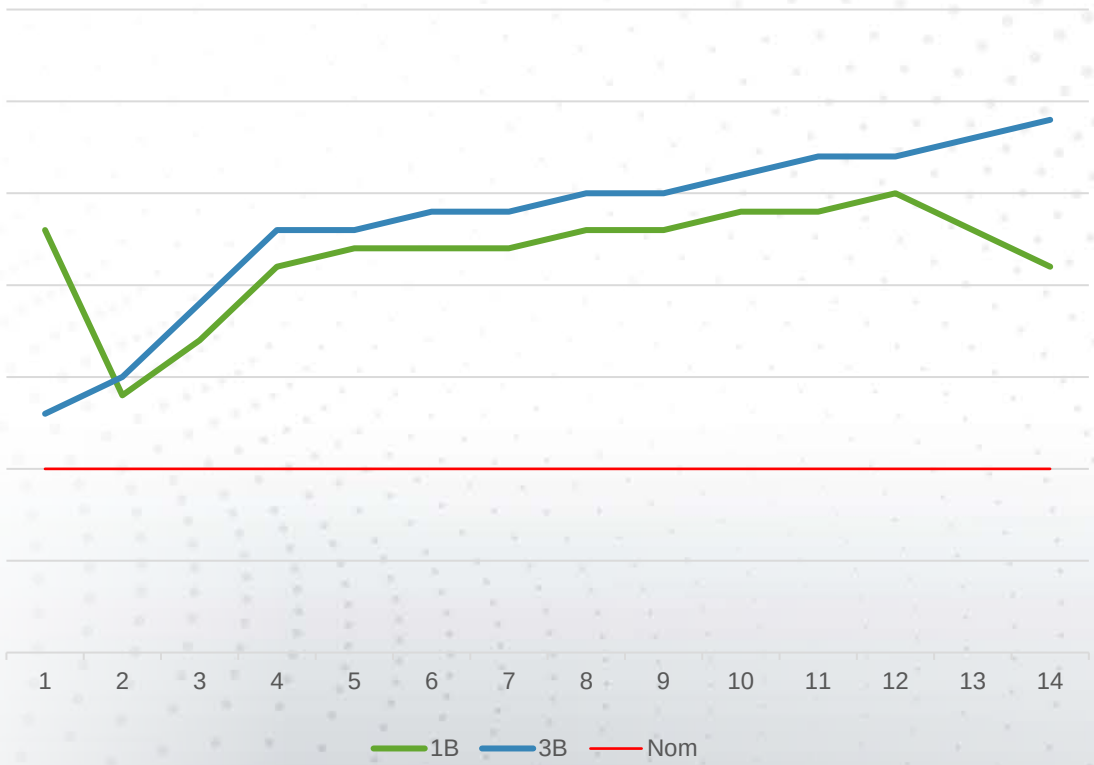
NDI of Frame #1



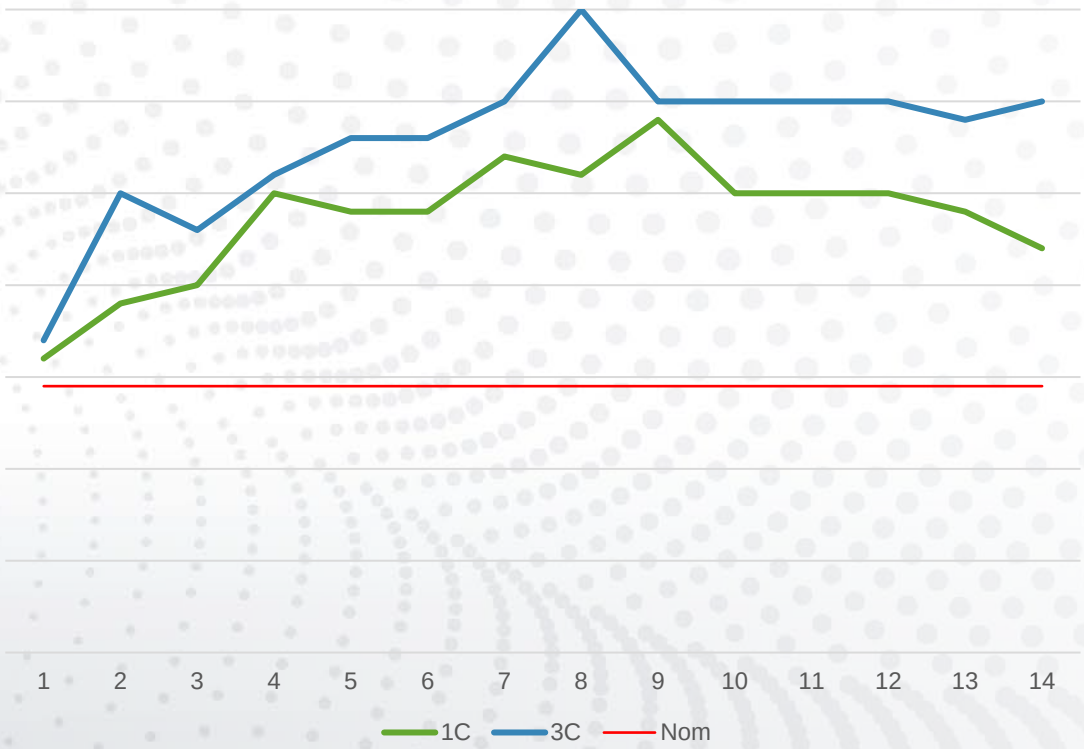
Thickness – First 2 Parts



Thin Web (area B)



Thick Web (area C)



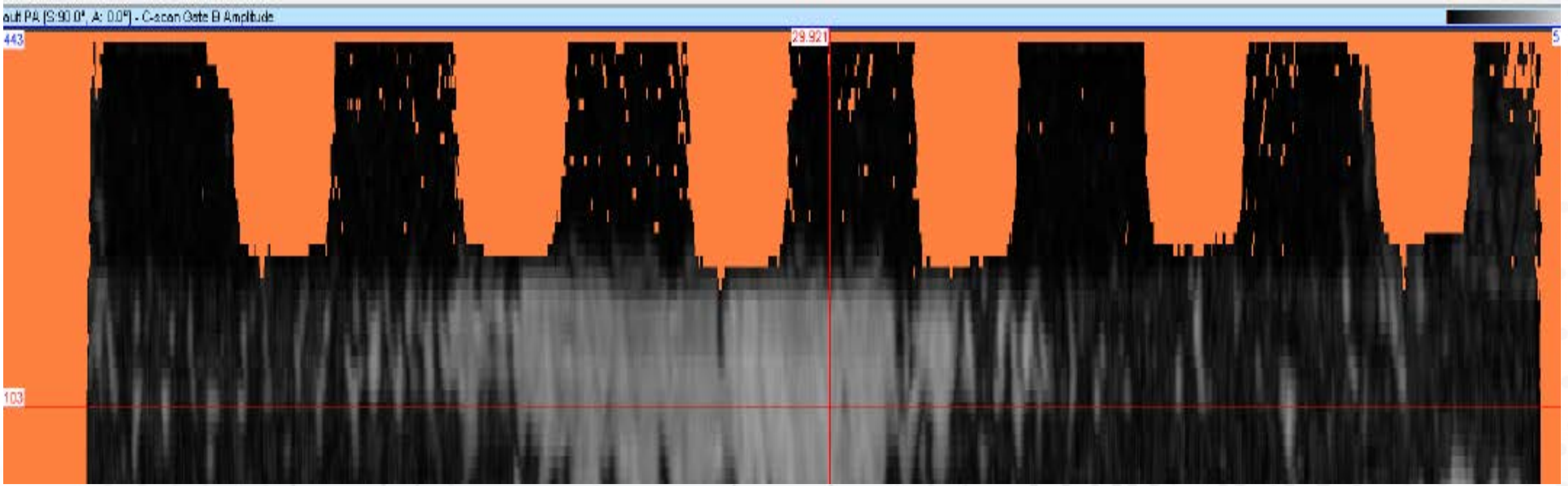
ECCN 9E991

Forming Trials

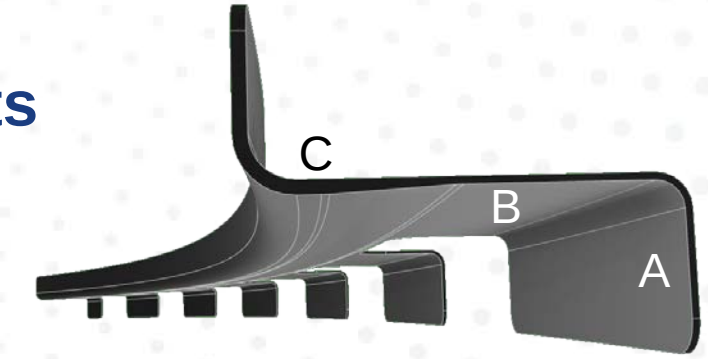
- Pressed 1 blank to test previous web pressure theory
- Part was marginally better
- Determined that blank orientation features were preventing complete tool closure & removed them

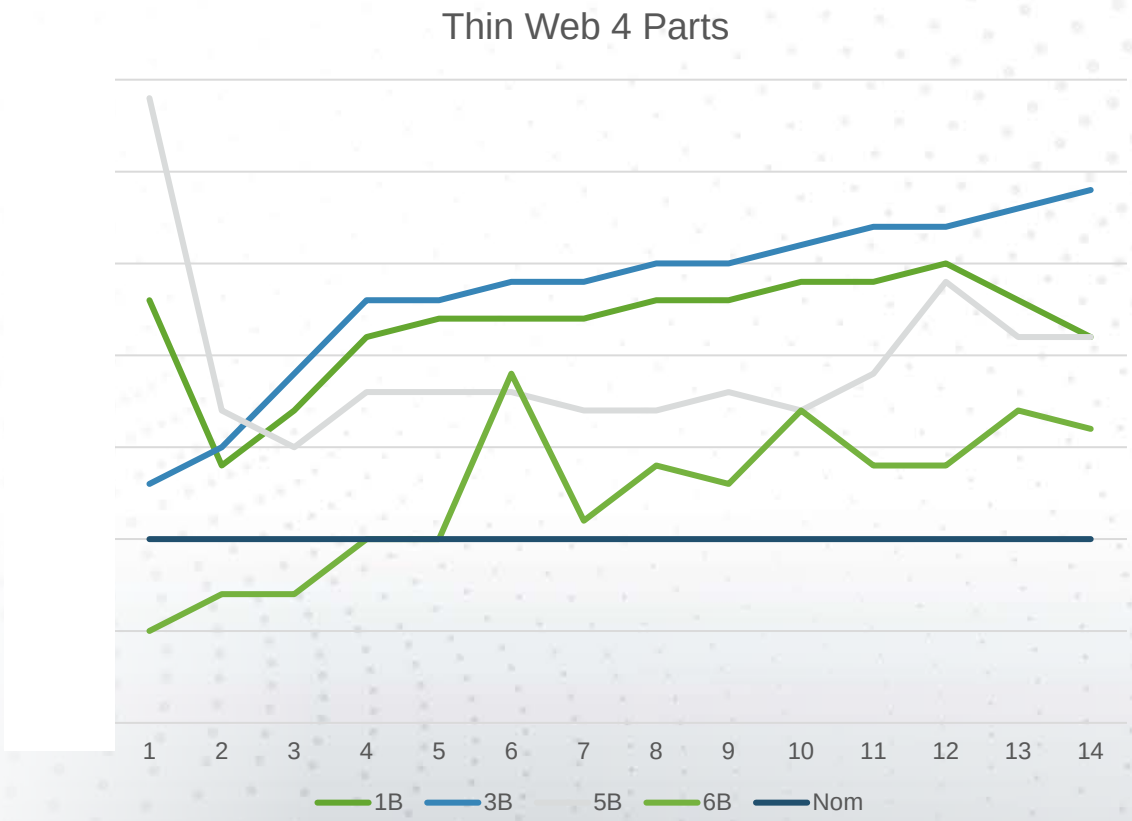
Frame after pressing – Full compaction in the thick part of the web

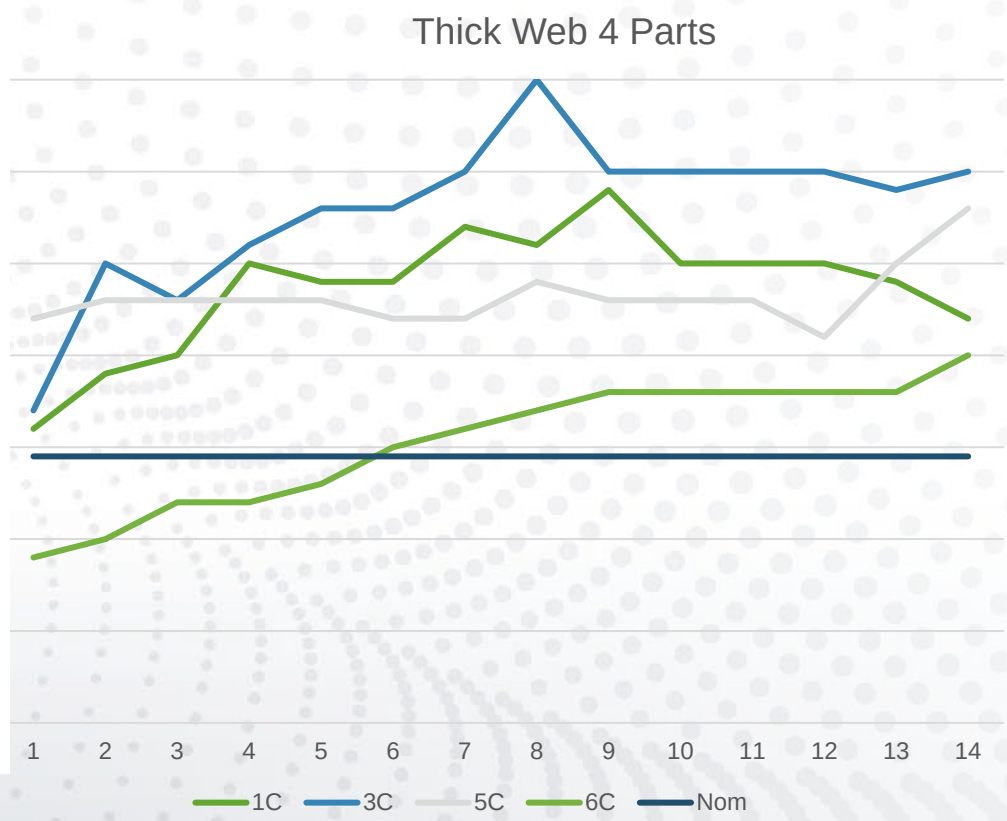
NDI of Frame #5



Thickness Charts – First 4 parts





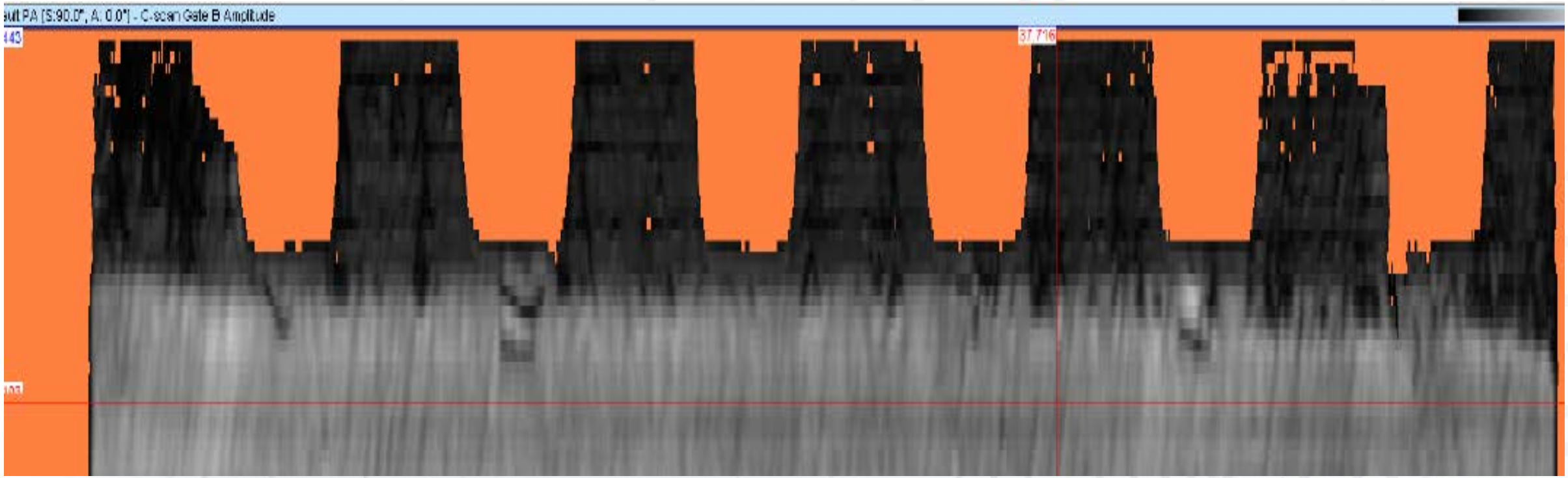


Forming Trials

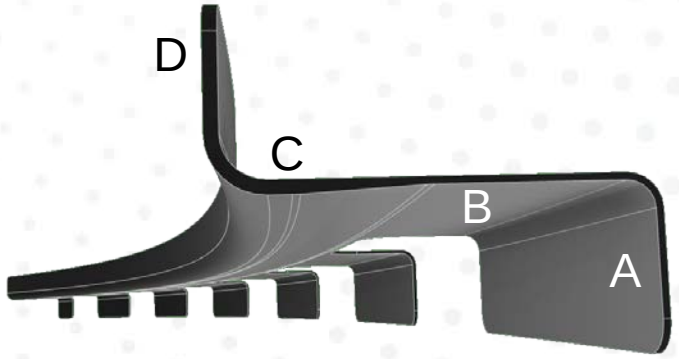
- Performed photomic evaluation of the part & determined that the blank was mis-located by 0.3”
- Pressed another blank which was our best part yet
- This part had no wrinkles in the web, confirming that we had the correct part alignment

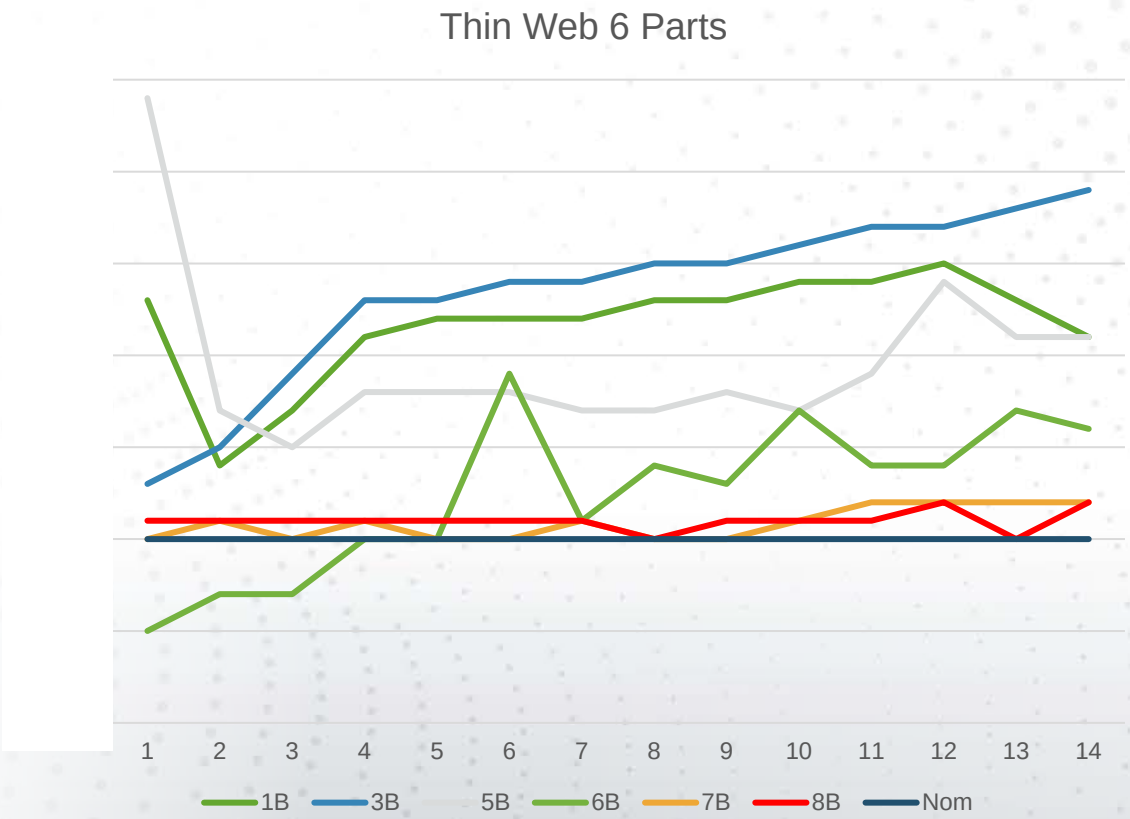
Frame after stamping. Good compaction on web after correcting blank alignment to dies

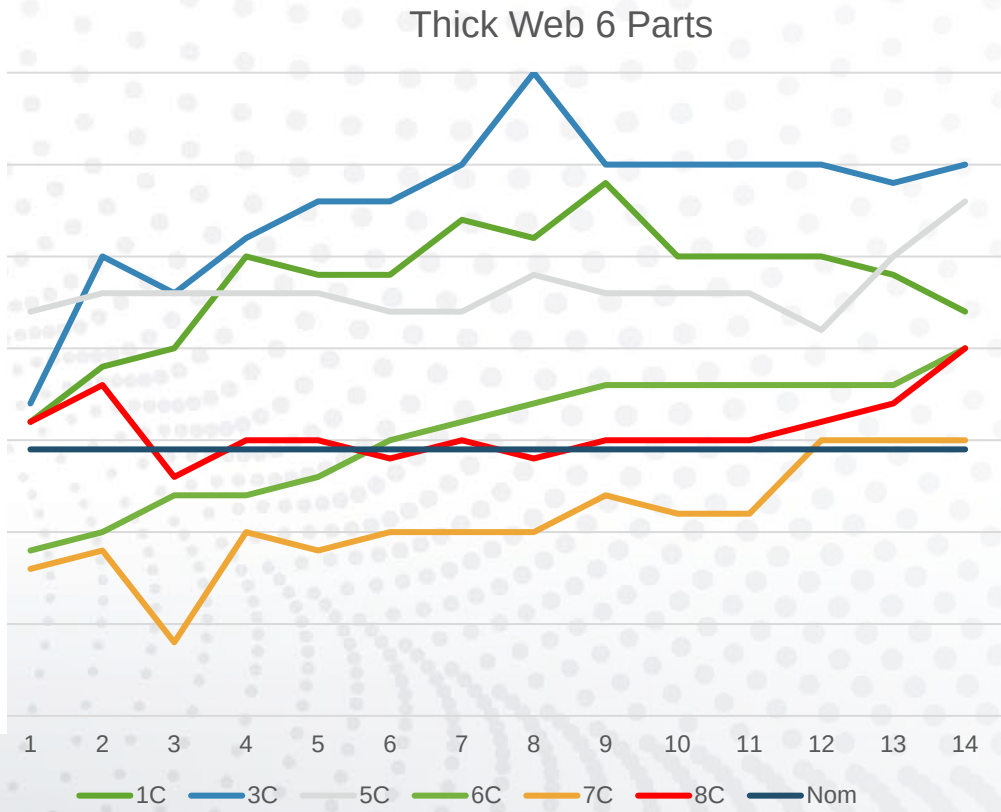
NDI of Frame #8



Thickness Charts – All 6 Parts

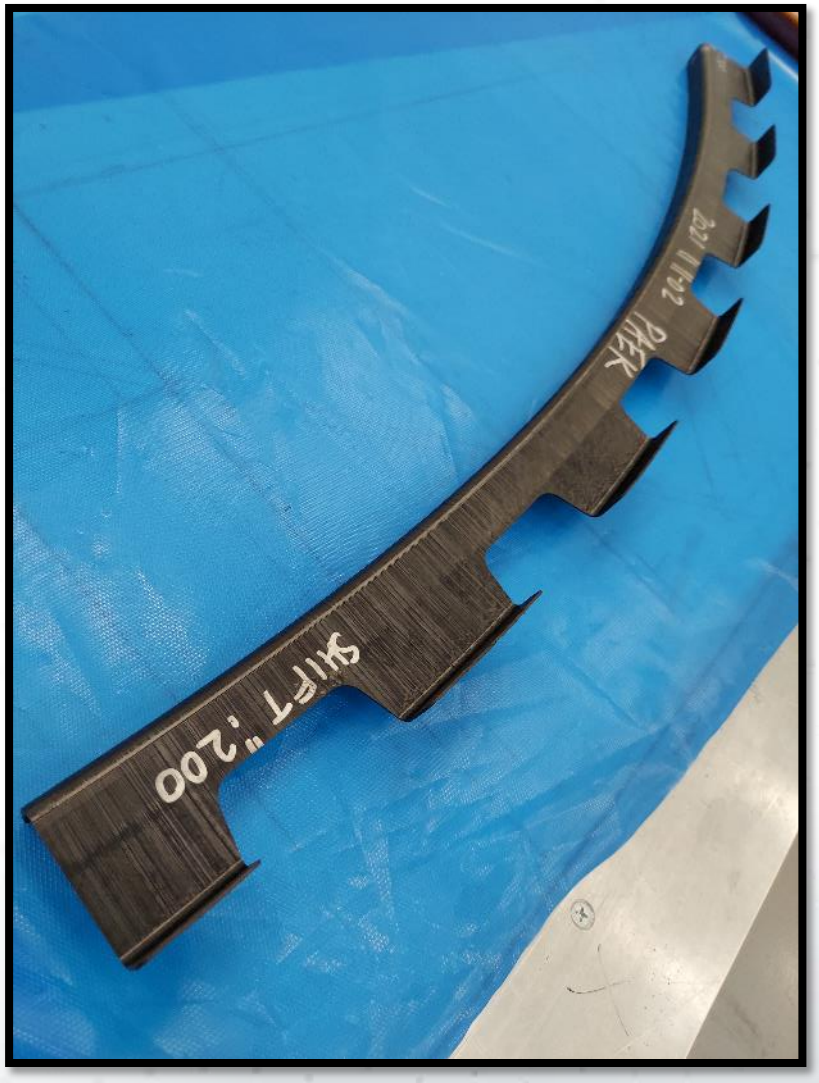


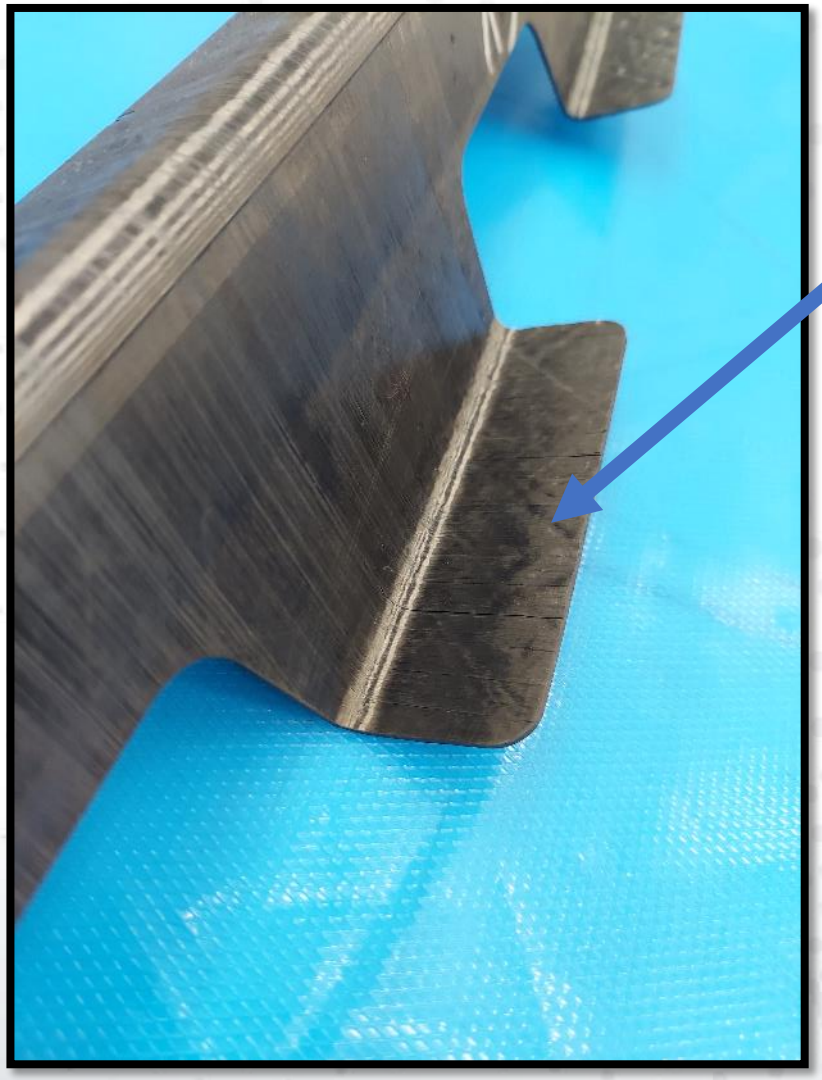




Initial Parts

Initial Parts

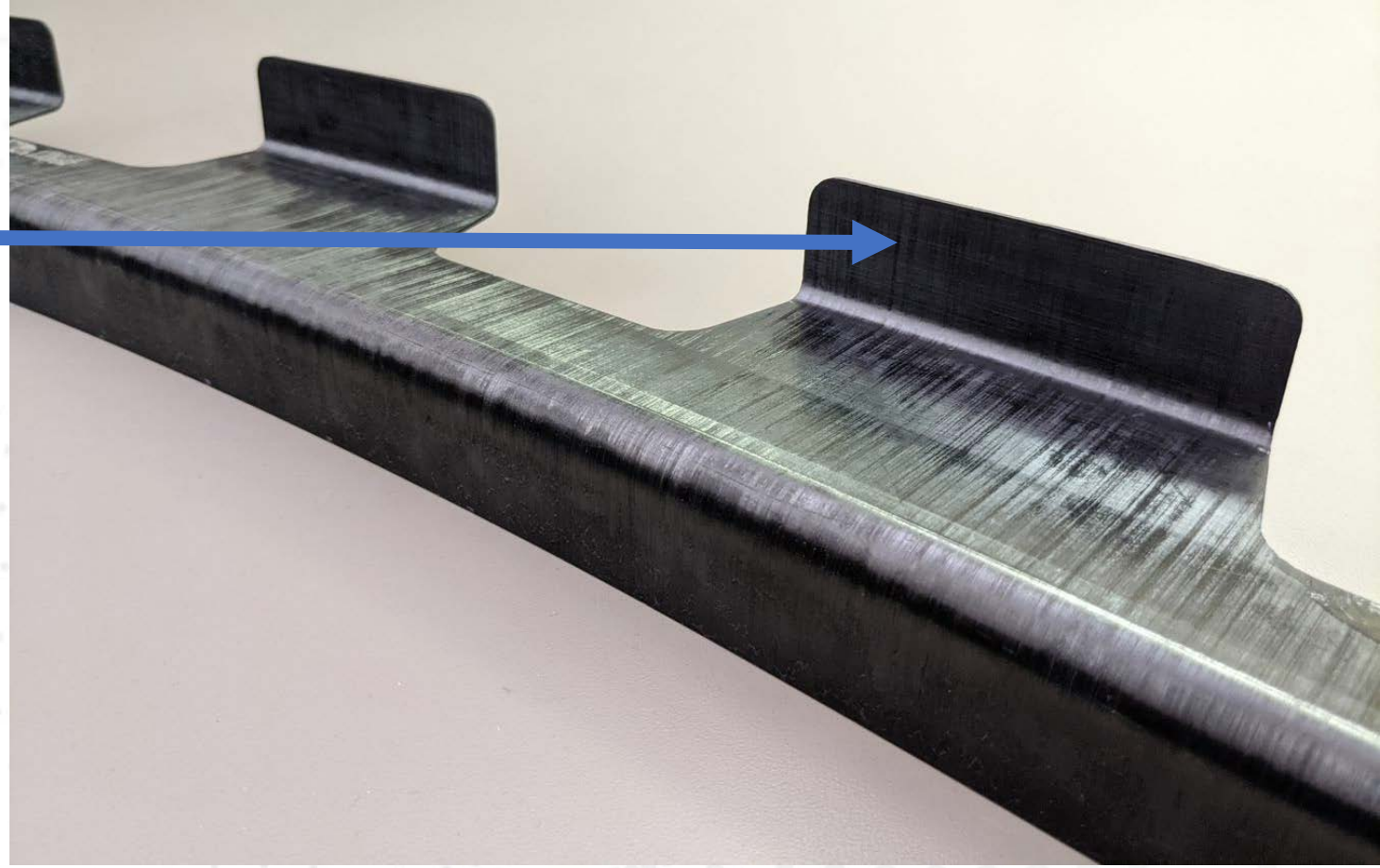




Flange Wrinkles

Latest Examples

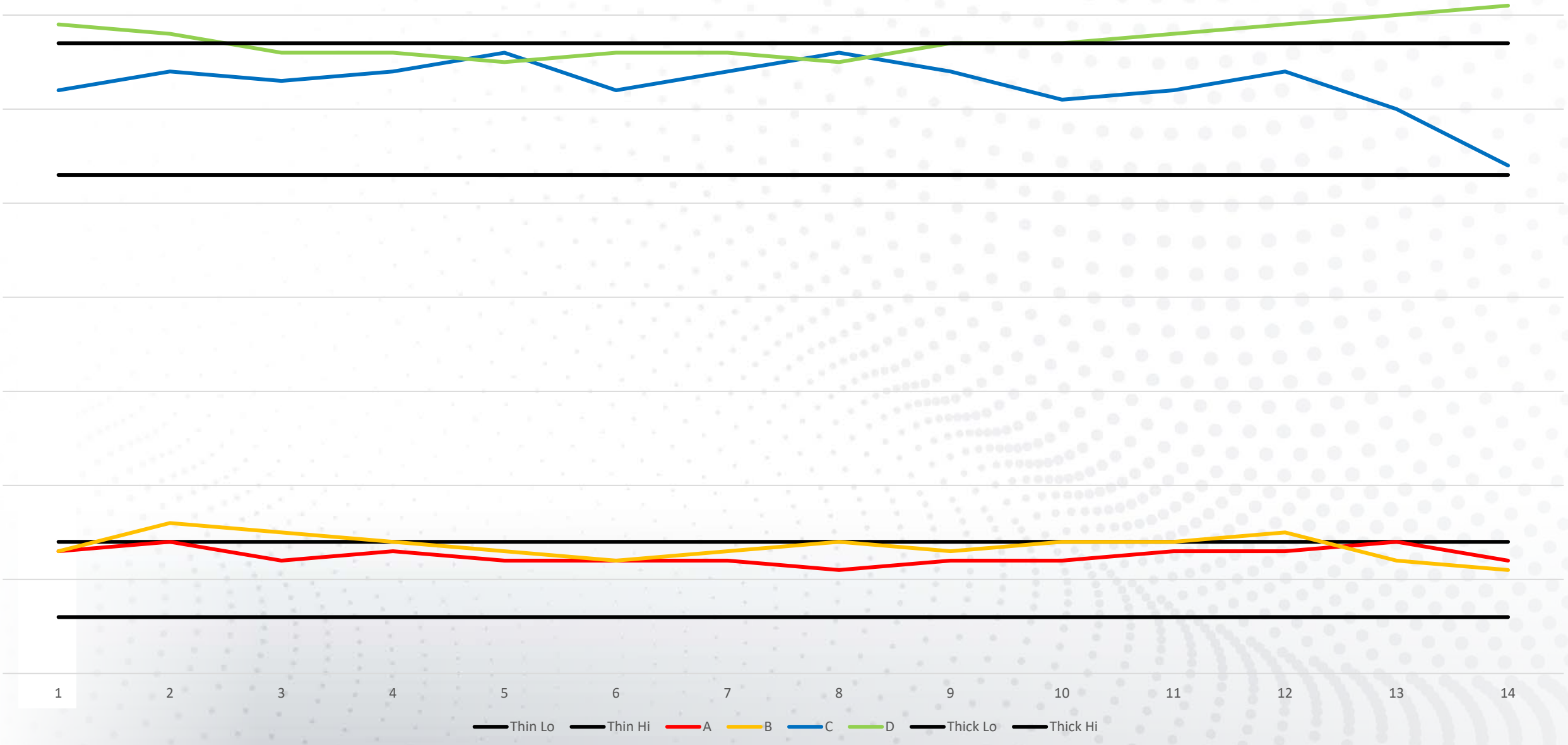
Good Flanges



Latest Examples

Formed Part Before Trim

Latest Frame Thickness Report



Future Work

- Investigate stamping tool scans for discrepancies
- Correct any discrepancies
- Modify blank holding fixture to accurately and repeatably hold the blank in the correct location
- Continue to make improvements to the process

Conclusions

- Blank alignment in the forming die is critical
- Blank loading/positioning process must be accurate and repeatable
- Matched metal tooling must be accurate

- If these processes are followed closely AFP + Press forming is an accurate and economical process for manufacturing structural airframe components

Thank You for your attention!

Ron Jones

Spirit Aerosystems